LEM WHITEPAPER R.1

How Local Energy Markets Benefit Distribution Utilities

(Revision 1)

Powerledger

Executive Summary

Revolutionising the Energy Landscape: From Grid Challenges to Localised Energy Trading and Sustainable Solutions.

The growing proliferation of distributed energy resources (DERs) within the global energy landscape has introduced significant challenges to conventional grid systems. DERs, being inherently decentralised technologies, often do not seamlessly integrate into the traditionally centralised and unidirectional power grid framework. Their unique characteristics necessitate bidirectional power flows, disrupting the established norms of centralised grid operations.

Historically, power grids worldwide have functioned as centralised systems, relying on centralised power generation facilities, unidirectional power transmission, and distribution. This model operated on the assumptions of predictable load growth and the ability to modulate dispatchable energy production. Centralised grid management offered control over power flow, typically overseen by control center operators.

Challenges linked to the variability of renewable resources and the influence of stakeholder demands for decarbonisation are compelling changes in the global energy markets. This shift is transitioning the energy landscape away from a centralised structure to one that is decentralised and characterised by increased agility.

The need to address congestion and enhance reliability in the face of surging Distributed Energy Resources (DERs) becomes evident as the diversity of DER device types continues to expand, contributing to congestion within distribution networks. More distributed energy resources (DER) are making congestion and reliability issues worse, which is speeding up the obsolescence of existing grid infrastructures.

In this white paper, which is update of our previous whitepaper [1]. It delves into the specific obstacles faced by distribution network operators in increasing DER adoption. It also explores the local energy markets (LEMs) and underlying technologies which can effectively tackle these challenges.

In this rapidly approaching landscape, consumers and prosumers are assuming a progressively pivotal role in LEM as the de facto operators of the balancing markets. These markets are essential for grid functionality and to achieve sustainability goals.

A new electricity market paradigm centered around localised energy exchange among peers has a pivotal role in ensuring resource sufficiency, alleviating congestion offers a compelling strategy to tackle these widespread issues within the industry

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1. Overview of Local Energy Market

1.1. Why Local Energy Market?

The proliferation of distributed energy resources (DERs) and the growing diversity of devices are intensifying grid congestion and reliability concerns. The annual expansion of DER capacity has exceeded that of centralised generation, a trend that is projected to persist until 2030 and beyond.

In response to these challenges, a localised energy trading paradigm is gaining prominence, granting consumers and prosumers the ability to use distribution-scale market to make money, while simultaneously helping the grid* and its suppliers.

Addressing congestion and reliability challenges is crucial given the widespread adoption of DERs and the growing variety of DER device types (e.g., water heaters, pool pumps) in distribution networks, which can contribute to grid congestion. These prevalent congestion and reliability issues, compounded by the increasing penetration of DERs, are causing existing grid infrastructures to become outdated.

By 2030, annual DER capacity additions are projected to nearly double those of new centralized generation capacity, as illustrated in Figure 1 [1]. Effectively managing non-dispatchable energy sources like rooftop solar photovoltaics (PV) is of utmost importance.

The existing grid infrastructure is insufficient to cope with these demands. New market mechanisms must emerge to address these challenges.

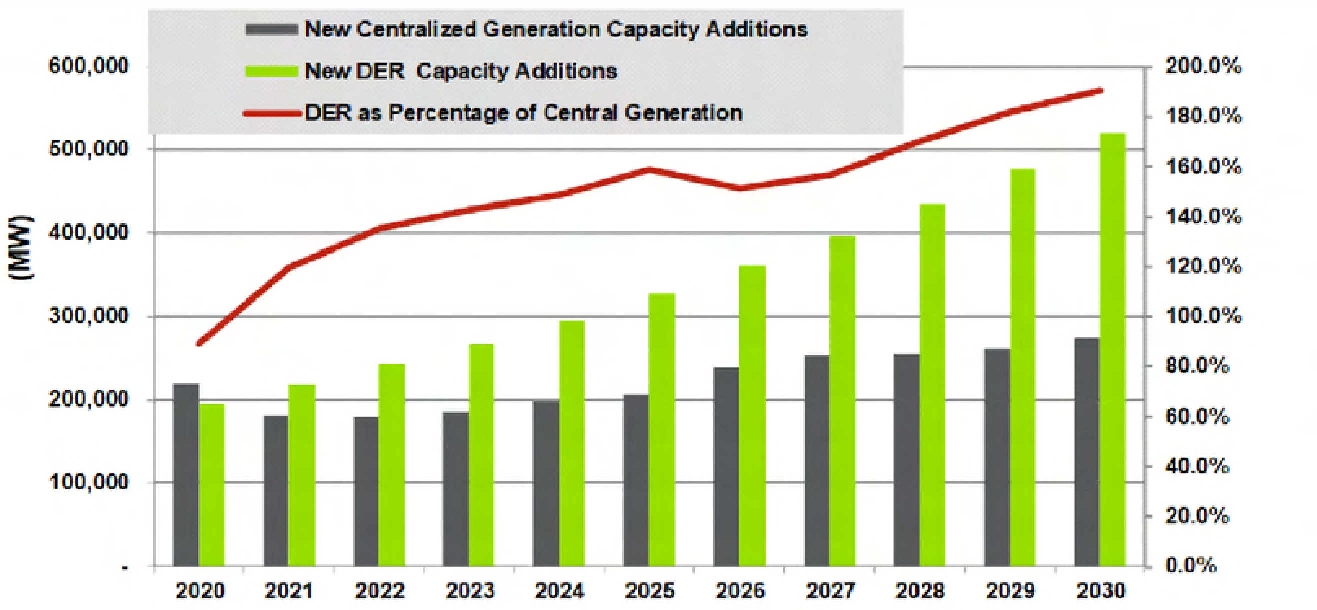

Figure 1 DER Versus Centralized Generation Capacity, 2020-2030

* This report uses DNSPs, DSOs, utilities and retailers synonymously. They refer to entities who manage the distribution grid and distribute electricity to their customers.

The widespread adoption of DER assets is imposing several operational and financial constraints on electric utilities. In addition to the aforementioned challenges, network congestion problems can result in curtailing DERs or even completely shutting down solar and wind resources to accommodate baseload fossil generators or short-term use of peaking plants. This traditional approach is flawed.

It leads to heightened costs and emissions. This is an unsatisfactory outcome for all the electricity system stakeholders. Moreover, it necessitates the inefficient use of reserves designated for frequency control and traditional ancillary services essential for grid stability, thereby placing undue stress on electricity market resources as a whole.

A new market based mechanism to address these challenges involves a localised energy trading paradigm among peers [2]. Such a mechanism empowers consumers and prosumers to actively manage their DERs, while providing resource adequacy, reducing congestion and increasing the social surplus. This shift will likely necessitate creation of a new market [3] with newer tariff restructuring, emphasising transmission and distribution fees over centralised generation.

The increasing presence of DERs, including various device types, is causing congestion and reliability problems in distribution networks. These issues, compounded by DER expansion, strain the outdated grid systems. Proliferation of DERs imposes operational and financial constraints on utilities, leading to network congestion, curtailment of DERs, and the inefficient use of resources. As a result costs rise and balancing the grid becomes increasingly more difficult. Ultimately, this could lead to a grid-failure.

1.2. Solutions with new energy paradigm

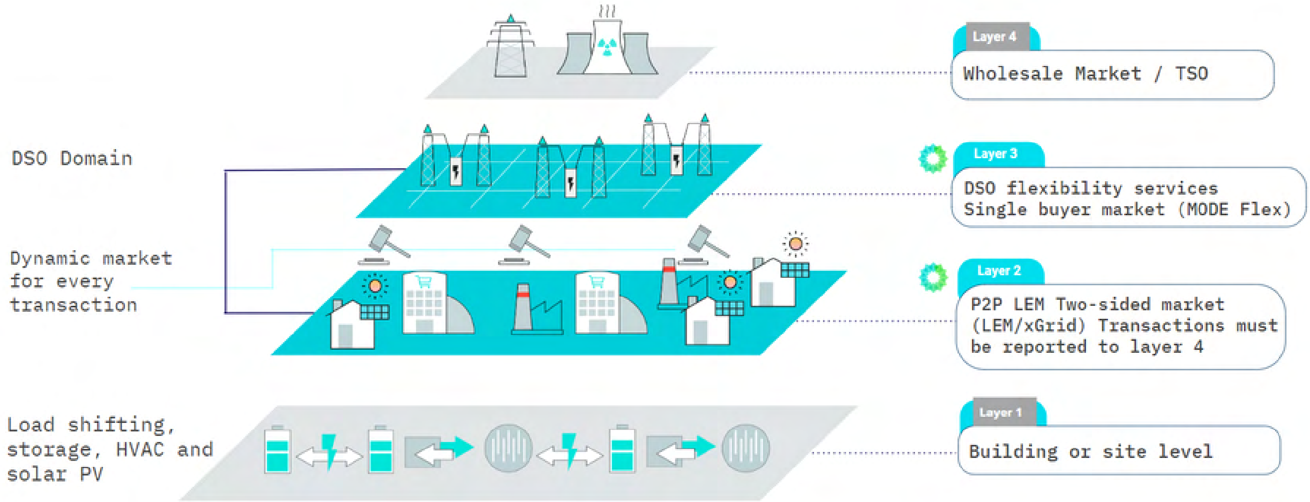

Figure 2 The Four Layers of Energy Markets (Layers 2 and 3 Focus on LEM Innovation)

The LEM, represented as Layer 2 in Figure 2, promotes P2P trading at competitive rates compared to grid buy and feed-in-tariffs. It relies on market price signals driven by renewable energy forecasts and regional flexibility market indicators. Participants trading above a certain power level can engage in Layer 3, the flexibility market. This forward-facing market, spanning week, day, or intraday horizons, enables DSOs to obtain flexibility from aggregated DER assets for alleviating grid congestion.

While both mechanisms aid DNSP/DSOs with grid congestion, LEMs (Layer 2) are a more cost-effective choice than Layer 3 flex markets. They cut grid imports and exports through P2P trading, addressing congestion, and facilitating voltage management. This minimises the need for budgeted incentives aimed at DNSP/DSOs for procuring flexibility, thus resulting in significant cost savings [1].

The electricity network can be viewed as a layered structure. This structure has the transmissions level wholesale grid at the top and decentralised elements at the bottom. In between, there are two other layers.

Such layers interact to ensure efficient and safe grid operation.

Layer 2, the LEM, promotes peer-to-peer trading based on renewable energy forecasts and regional market prices. Layer 3, the regional flexibility market, sources flexibility from aggregated DER assets to relieve grid congestion.

LEMs provide a cost-effective solution, reducing imports/exports from and to the wholesale grid, reducing congestion, and financially making all stakeholders better off.

The LEM (Layer 2) facilitates P2P trading with competitive rates. Layer 3 is the distribution scale flexibility market. Layer 4 is the wholesale market.

LEMs are more cost-effective solutions (than layer 3 or 4) for orderly integration of DERs.

LEMs reduce imports/exports, ease distribution congestion, and aid in voltage management. They are win-win-win solution for all stakeholders.

1.3 What is a Local Energy Market?

A Local Energy Market (LEM) is an automated platform designed for peer-to-peer (P2P) electricity trading. This platform brings together a community of geographically close consumers and electricity producers, often referred to as "prosumers," who engage in energy exchange using distributed energy resources (DERs) like on-site solar PV systems and batteries.

P2P trading based transactions occur continuously 24/7 throughout the year and typically offer competitive pricing compared to grid purchase rates and the Feed-in Tariff (FiT).

The automated LEM platform facilitates P2P trading among participants, who act as buyers and sellers to balance supply and demand within a specific grid area. LEM participants are categorised into three groups: consumers, prosumers with solar PV, and prosumers with solar PV and BESS. These participants are registered in the LEM through their respective retailers and continue to receive their electricity bills as usual.

The LEM allows participants to trade energy with each other through the LEM trading platform, where buy and sell offers are matched in forward-facing time intervals. Buyers place bids in the LEM at rates lower than their tariff rate, while sellers bid at rates higher than the FiT. The traded volumes and prices are communicated to the retailer(s) for billing [4].

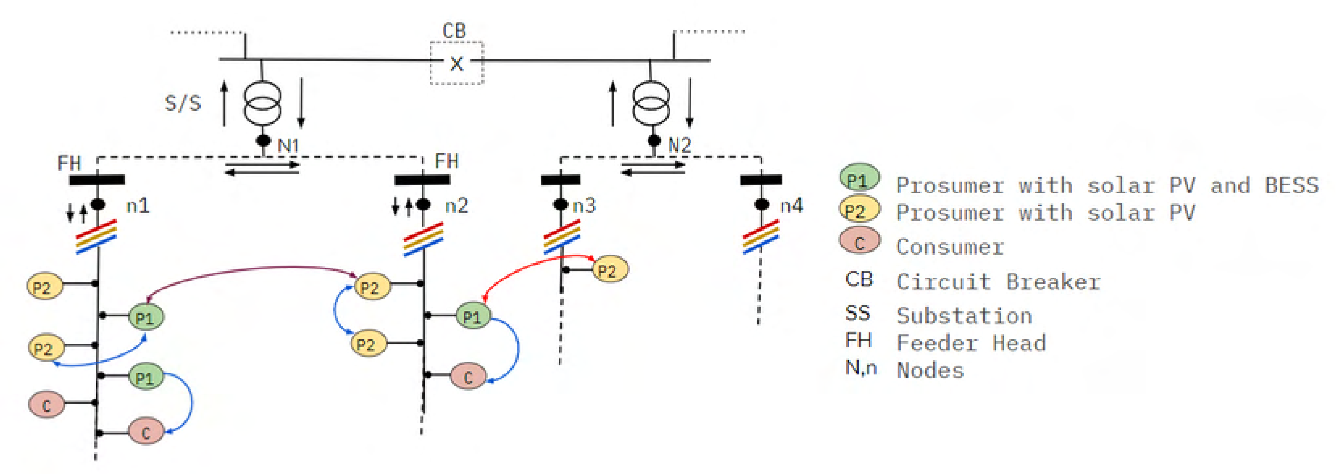

Figure 3 The Four Layers of Energy Markets (Layers 2 and 3 Focus on LEM Innovation)

As illustrated in Figure 3, the LEM architecture comprises three participant categories served by two substations and four feeders. LEMs inherently promote prosumer energy self-sufficiency.

In this innovative approach, the LEM leverages the infrastructure of the current electricity distribution system to facilitate power exchange among prosumers at a rate determined by themselves.

In exchange for this transactional capability, participants incur a fee or charge paid to the DNSP, which either owns or manages the distribution infrastructure and, in some instances, operates the LEM platform as well. In the LEM, the pricing for each kilowatt exchanged is determined by both the seller and buyer, constituting a two-sided market that functions similarly to an automated stock market [5].

2. Blockchain Technology in a Local Energy Market

2.1 What is Blockchain and how does it work?

Blockchain technology is a decentralised digital ledger system known for its resistance to tampering. It functions by documenting transactions across a computer network, forming a sequence of data blocks interlinked through cryptographic hashes. This technology offers transparency, security, and trust, all without the need for a central governing body. When a new transaction is registered, it becomes an indelible part of the chain, making it exceedingly difficult to manipulate or erase any data, thereby preserving the ledger's integrity.

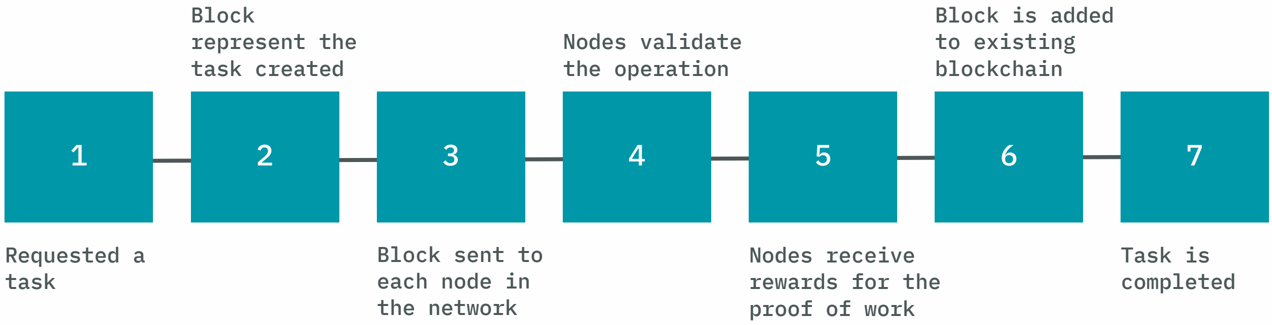

Figure 4 How blockchain works

The depicted process in Figure 4 illustrates how blockchain operates, beginning with a task request and concluding once the task is finalised. In a blockchain network, data is not subject to control by a central entity; instead, it is distributed across multiple network nodes. Each node upholds its own copy of the ledger, promoting robustness and minimising the risk associated with singular points of failure. Notably, every transaction documented on the blockchain is visible to all participants in the network, fostering transparency and bolstering trust among users. This framework empowers users to independently validate transactions, further enhancing the network's credibility.

In the blockchain network, the nodes communicate together to validate and send transactions through smart contracts. These smart contracts can send and receive monetary value, energy-related, or even verify identity. Smart contracts automatically execute transactions into the ledger based on previously determined inputs like the price for a kW of energy and a participant's willingness to buy at that price [6].

These transactions are verified by the other nodes on the network as opposed to a central clearinghouse third party. Blockchain is often considered to be the underlying technology for P2P energy trading and LEMs, however, this is misunderstood. Blockchain is not necessary for the creation of a LEM; it would be possible to use a standard database to keep track of all transactions that occur across a LEM. Nevertheless, utilising blockchain provides key benefits due to the way the technology is structured and how it can facilitate a decentralised network and database [7].

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“Blockchain, Artificial Intelligence and machine learning are complementary technologies to unleash the power of LEMs” says Vivek Bhandari, CTO, Powerledger

2.2 Powerledger Blockchain in Local Energy Market

Powerledger Blockchain's (PLBC) decentralised nature enhances efficiency, reduces costs, and ensures transparency and security through self-evaluation of transactions. The blockchain technology records and verifies participant transactions in real time using smart meter data and automates them using smart contracts, saving time and reducing friction in Local Energy Markets (LEMs).

As the energy market becomes more decentralised, blockchain provides a secure database, enabling partners and regulators to access and share data.

"PLBC can process a very large number of transactions at affordable costs while optimising transaction efficiency", says John Bulich, Co-Founder & Technical Director, Powerledger

Figure 5 PLBC Node distribution across the globe

Powerledger blockchain (PLBC) has recently switched from Ethereum based chain, which historically has been capable of tracking 10 to 12 transactions per second, to a fork of Solana, which processes between 50,000 and 65,000 transactions per second while also using less energy in the process.

PLBC is primarily used to achieve high scalability, throughput and extremely low transaction costs, while maintaining energy efficiency[8].

PLBC is a high-performance, permissionless, proof of stake public blockchain and with further improvements for energy use cases.

The existing network capacity of PLBC exceeds 20,000 transactions per second (TPS). Through Solana has been tested at potentilly 1.2 million TPS or 600,000 TPS after deduplication.

This is a significant improvement compared to Ethereum's current capacity, which is limited to approximately 10 to 30 TPS. In addition to TPS, another appealing aspect of PLBC is its cost-efficiency [9].

The minimal cost for processing a transaction is 0.000005 native tokens (POWR), equivalent to approximately $0.0000075 USD per transaction or more than 13,000 transactions per US cent.

Current nodes of PLBC across the globe are shown in Figure 5.

Each transaction between participants is recorded in time to the PLBC and verified using smart meter data. With the addition of smart contracts, the transactions between participants are automated, therefore saving significant time that would ordinarily be spent setting and changing buy/sell preferences throughout the day.

As there are many transactions between participants in a LEM which could amount to unnecessary 'friction', or overload to the market, blockchain is a welcome addition to the system.

As the energy market continues to change towards a decentralised system, and DSO/DNSPs number of partners grow, PLBC offers a secure database that permissions these partners, even regulators, to access and share data.

2.3 LEM integration with PLBC

Local Energy Markets (LEMs) employ blockchain technology, enabling secure decentralised energy trading without central authority reliance. LEMs, integrated with blockchain, shift towards decentralised, edge-centric market structures, distinct from grid-centric models.

They enhance reliability with clean prosumer assets, working synergistically with Virtual Power Plants (VPPs) and transactive energy (TE) concepts, expanding generation control at the distribution level, revolutionising grid operations.

A Local Energy Market (LEM) operating on a decentralised community model offers substantial advantages, including enhanced grid stability and reduced congestion. When integrated with blockchain technology, LEMs facilitate a smooth transition from centralised to decentralised market structures, as depicted in Figure 6(a) [1]. When integrated with flexibility markets, LEMs can unlock synergistic benefits that exceed the cumulative impact of these components.

Blockchain technology, widely employed in Transactive Energy (TE) solutions and LEMs, has the potential to become a universally adopted standard in grid operations. Blockchain facilitates automated accounting and information sharing within LEMs, ensuring secure transactions of data, energy, and value without the need for a central trusted authority.

This trustless system guarantees error-free financial settlements, eliminating the necessity for centralised oversight.

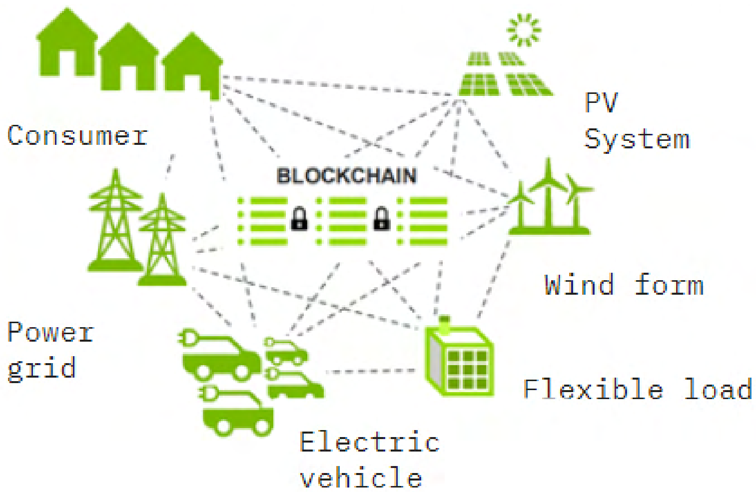


Figure 6 (a) Decentralised market structure

The proposed LEM integration with blockchain streamlines the bidding process starting with users submitting their bids is shown in Figure 6 (b). The platform's trading engine performs energy matching, execution, and settlement tasks for every time interval. Subsequently, the platform generates transactions reflecting those outcomes for storage on the blockchain.

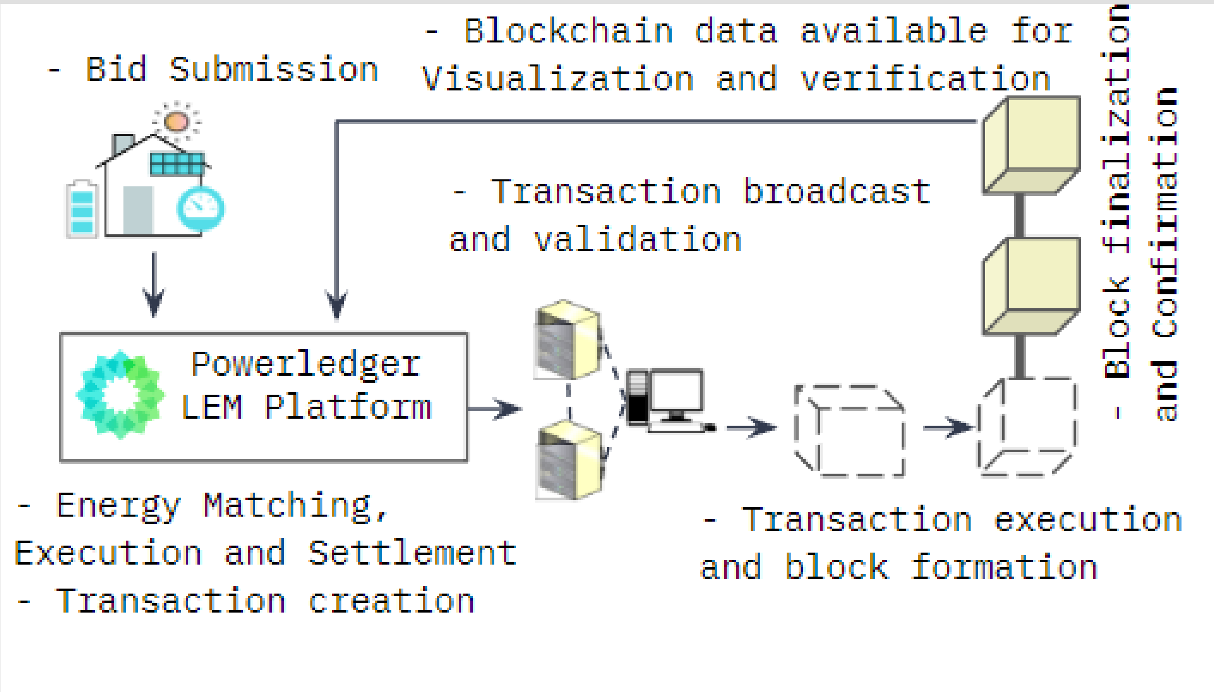


Figure 6 (b) LEM integration with Blockchain technology

These transactions undergo broadcast and validation within the blockchain network. Through the network's consensus mechanism, transactions are executed and organized into blocks. Once formed, blocks undergo finalisation and confirmation processes within the blockchain network, ensuring immutability and security. The data stored in these blocks becomes available for participants through the user interface (UI). Users can easily access and view the confirmed records of their energy transactions, promoting transparency and trust within the LEM framework [10].

3. Implementation of Local Energy Market - A Case Study

3.1. LEM case study - assumptions

Powerledger conducted a comprehensive analysis of the dynamics of a local energy market within the unique context of the Indian market over the period of one year.

With 1,000 participants, this analysis shows the advantages of energy trading among distinct participants, including commercial and domestic users, with and without solar installations, and a community battery. The social and financial benefits of LEM for all the stakeholders are discussed, compared and evaluated in relation to a business-as-usual (BAU) scenario.

Framework

The proposed LEM architecture as shown in Figure 7 consists of following set of participants:

Domestic consumers - 500	Domestic Prosumer - 350
Commercial consumers - 100	Commercial Prosumers - 50
Community battery - 1 (Capacity - 3,000 kWh/2,000 kW)	

- All participants have the ability to exchange electricity with each other and with the community battery.
- Domestic participants include residential single households and multi-apartment blocks, while commercial participants encompass SMEs, schools and municipalities.
- Both groups have consumers who can import electricity and prosumers who can import and export electricity.
- The DSO-owned battery serves as a backup trade option for load and solar imbalances.

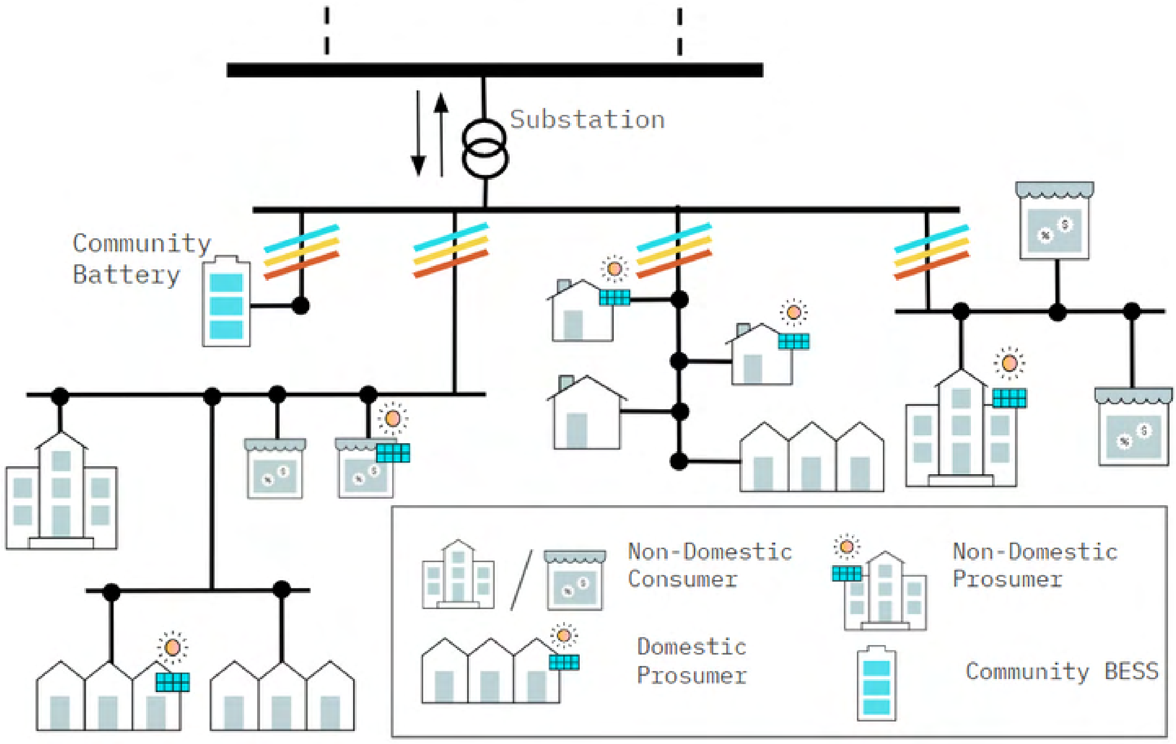


Figure 7: High level diagram of the LEM trading group

Load and Generation Data

The trading is based on historical load and solar meter readings. Readings are derived from the distinctive attributes of each participant category. The data mirrors the typical energy consumption patterns throughout different months of the year, is shown in Figure 8.

43MWh

The average daily load of the community

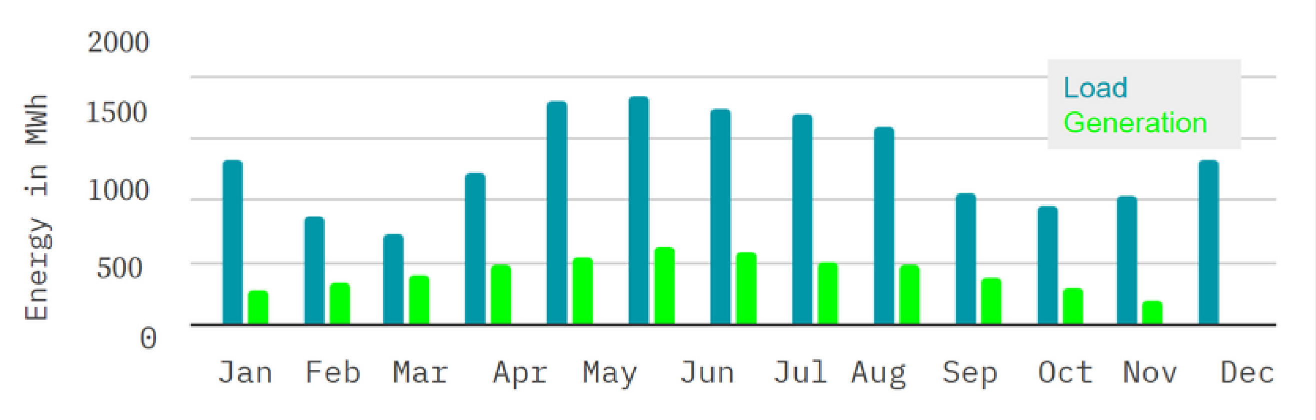


Figure 8: Monthly load and solar totals

Electricity Tariffs

P2P energy transactions between participants are conducted within their usual grid buy and sell rates offering a guaranteed benefit. Domestic participants pay slab rates between 0.024 and 0.085 USD/kWh based on their demand. Commercial participants pay a flat tariff of 0.090 USD/kWh [11].The final transaction is settled based on buyers price, sellers price or an midway-average of both.

between 0.024 and 0.085 USD/kWh

Slab rates of domestic participants (based on demand)

0.090 USD/kWh[11]

Flat tariff paid by commercial customers

Setup

The participants are assumed to be distributed among multiple feeders in the distribution network below a substation. This ensures that P2P trades are also reflected in a reduction of import and export at the substation level. Additionally, the connection to the backup grid allows the import and export of deficient or surplus energy from the LEM. Due to the close proximity of participants, any losses from energy transfers are neglected in the study [12].

3.2. LEM case study - methodology

Trade matching between participants follows a merit order bid stacking of buy and sell bids. Buyers submit load quantities with a buy price, sellers submit* solar excess quantities with a sell price.

Highest buy prices are matched with lowest sell prices to guarantee participants that submit high buy/low sell prices greater chances of being matched in a trade. In the first step, load and solar quantities are matched.

Subsequently, in two additional steps, the community battery either charges from excess solar generation or discharges to cover unmet load requirements.

Finally, any remaining imbalances are either imported or exported to the grid at standard grid tariffs. This sequence optimises benefits for both participants and the grid.

*buyers and sellers submit the energy quanta automatically using the forecasting application

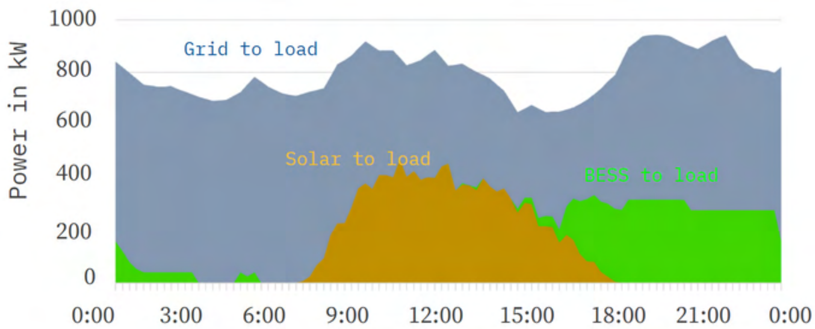


Figure 9: Daily profile of load, solar and battery

P2P Matching

P2P energy trading is performed according to a predefined trading rule stack which leads to an optimum outcome for participants and the grid. Participants can submit buy and sell bid prices which determine the final P2P price and therefore influence the energy cost.

Bids are matched based on a **merit order stacking of bid prices** to ensure the most favourable combinations of buyers and sellers. Buyers are ordered by highest submitted prices, while sellers are sorted based on lowest sell prices. This mimics the stacking of generator capacities in many wholesale energy markets such as the National Electricity Market in Australia [4].

Settlement in the case study is done based on the buyers price, but can alternatively also be based on the seller's price or an average of both. If buy and sell prices don't match (the buy price is lower than the submitted sell price), the trade will not be executed.

Trading Sequence

The transactions are based on a set of different rules, which influence subsequent rules.

a) Solar to load
In the first step, the inflexible load requirements of all participants and the solar excess of prosumers are matched.

b) Solar to battery
During a second step, any surplus solar energy that has not been allocated in the previous step is paired with the available battery capacities, with the primary aim of minimising excess energy exports to the grid.

c) Battery to load:
Similarly, in step three, unsatisfied load requirements from step one are matched with available battery discharge capacities to ensure as little as possible is imported from the grid.

d) Balancing with grid:
After the P2P has concluded, final balances (remaining surplus or deficiencies) are settled with the grid. The daily load, solar PV generation and battery SoC profiles are shown in Figure 9. Altogether, this trading sequence calculates the outcome for balancing solar and load. The battery dispatch is optimised based on demand and supply peaks to ensure a smooth demand profile.

Objectives of the case study

The case study aims to illustrate several core objectives. Firstly, it seeks to demonstrate the **potential of LEMs in enhancing energy distribution at the community level**. This includes showcasing how LEMs can support renewable energy integration, allowing local producers to sell excess energy within the community, thereby creating a sustainable and resilient energy ecosystem.

Secondly, the case study evaluates the **economic benefits for participants**, including cost savings and potential revenue streams. Another critical objective is to explore the **role of blockchain technology** and smart contracts, in facilitating secure, transparent, and efficient energy transactions within LEMs and evaluating their cost impact. Lastly, the impact on local **self-sufficiency and greenhouse gas reduction** is evaluated [13].

3.3. LEM case study - grid benefits

The LEM uses an average of 60% of the rated energy capacity of the battery, ensuring safe limits are kept at most times to reduce degradation.

The battery enables the achievement of import and export peak reductions, leading to a greatly more predictable profile for the whole community while alleviating strain on the local network.

For the DSO this can translate into a deferral of capital expenditure (CapEx) investments in network infrastructure.

Community Battery

The community battery charges and discharges on a daily cycle from **13 to 74 %** from the prosumers excess solar energy as shown in Figure 10. This translates into a total of **1,890 kWh cycled through the battery dail**y with a round trip efficiency of ~89 % (688 MWh annually).

The battery buys and sells at grid rates to ensure maximum benefit for the battery owner. It therefore does not provide any cost reduction for the participants, but increases the utilisation of their solar energy.

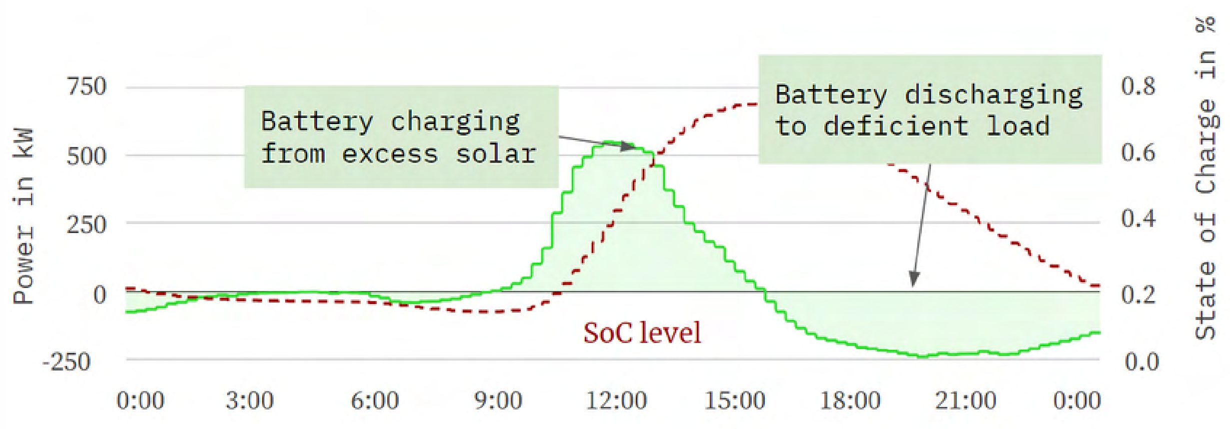


Figure 10: BESS charging and discharging sequence

The daily income for the battery amounts to ~11 USD, leading to an annual income of 3,960 USD. This would not suffice to recoup the battery investment cost, however, it should be noted that the main objective for the battery is not to achieve a quick PBP, but providing grid and community benefits as it is owned by the DISCOM which are detailed in subsequent sections.

Balancing the Demand Profile

Deployment of the community battery and participation in a LEM yields vast reduction in grid exports and imports. **Comparing schema LEM and BAU, total daily grid import is reduced by ~1,678 kWh, whereas daily grid export is reduced by ~1,885 kWh on average** over the whole year. The difference between both figures is a result of the round trip efficiency of the community battery.

The battery operation shifts the demand from evening peak hours to midday to make use of low-cost solar surplus. This translates into a reduction of daily peak demand and export, leading to a balancing on the local level which reduces the requirement for network infrastructure and network services at higher grid levels. Additionally, it reduces the step changes of demand due to the fluctuating output of solar PV thereby addressing the increasing extremity of the duck curve.

The schedule of the battery in the case study is optimised to address peak load and export specifically, but can alternatively also aim at the highest return for the battery by charging on lowest and discharging on highest prices. In the LEM, similarly to wholesale markets, those mostly coincide with highest demand as the highest number of bidders is competing for energy during those intervals.

As shown in Figure 11, **the average peak demand is lowered by 271 kW, the export by 420 kW** on average for the whole year.

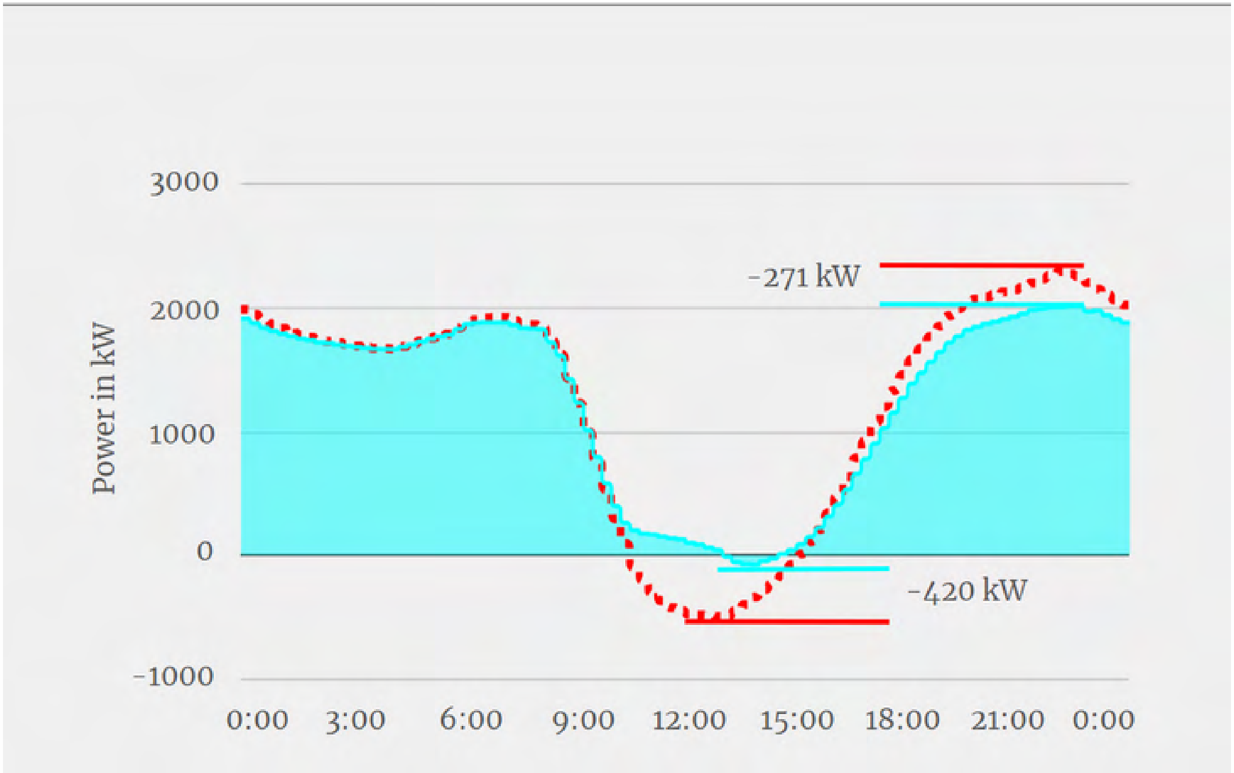


Figure 11: Net demand with import and export peaks

3.4. LEM case study- cost reduction

Electricity costs are reduced on average by 12 % per participant. This reduction equates to an annual average of ~50 USD per participant. The individual savings vary amongst all participant groups with higher benefits for prosumers.

However, the LEM contributes substantial bill reductions even for consumers without any DER assets.

The DISCOM additionally can save on infrastructure cost for distribution network equipment, which can amount to USD 12,000 for the transformer alone.

Electricity Cost Reduction for Participants

The high grid buy tariffs of commercial participants enables them to offer lucrative buy prices to domestic prosumers, who pay lower grid rates in slab categories and receive net metering for surplus energy. Domestic participants with higher consumption have the ability to bid at LEM rates below their current slab rate to buy from prosumers in a lower rate category. Nevertheless, the highest share of electricity is bought by commercial participants who generally have higher demand and offer higher prices [14].

Altogether, all participants benefit from the LEM, however the benefits vary between the participant categories. In relative savings, domestic prosumers gain the highest benefit due to their ability to sell at elevated prices as well as buy at reduced prices. The savings results are displayed in table 1, and electricity cost comparison is shown in Figure 12.

Average **bill reduction are around 12 %** across all participant groups.

This translated into **total annual savings of 32,400 USD for domestic participants, and 18,000 USD for commercial participants.**

Domestic prosumers are able to turn a negative bill into a positive bill in the LEM case through the generation of high sell prices to commercial buyers.

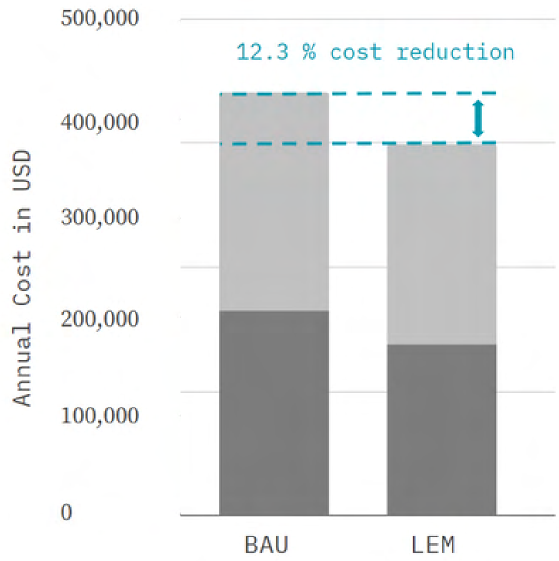


Figure 12: Electricity cost comparison

Participant Group	BAU - Electricity Cost	LEM - Electricity Cost
Domestic Consumer	188,897 USD	177,597 USD
Domestic Prosumer	9,550 USD	-11,777 USD
Commercial Consumer	134,821 USD	125,532 USD
Commercial Prosumer	75,571 USD	67,293 USD

Table 1: Electricity Cost Savings Overview

Reduction of grid infrastructure cost

Reducing peak import and export translates to less strain on the local network. For instance, the modeled community's **annual peak load of 1,825 kW drops to 1,650 kW in the LEM**, allowing for a lower capacity distribution transformer to safely supply the LEM.

Typically, substations are designed to handle peak loads with an additional 25-50% margin. Lowering the peak load reduces the required capacity rating. A transformer for the BAU community would require a rating of ~2,200 to 2,700 kVA [15] with a power factor of 0.8, compared to ~2,000 to 2,500 kVA would be sufficient in the LEM case.

Given step changes of transformer capacity of 500 kVA, the BAU case would require a transformer with 2,500 kVA capacity that cost around 40,800 USD. While the LEM would safely operate with a rating of 2,000 kVA that cost 28,800 USD.

The calculated LEM example translates into a **CapEx saving of 12,000 USD for the transformer alone.** The transformer is one example among many infrastructure pieces, such as switchgear, protection devices, or safety systems that can undergo cost reductions through LEM.

Moreover, the savings from one LEM can be amplified if implemented in multiple locations, and further peak demand reductions can lead to greater savings, justifying investments in additional BESS or other controllable DER.

3.5. LEM case study - Sustainability benefits and blockchain cost

The self sufficiency was increased by 5 % over the annual average, thereby reducing the imports of carbon-intensive energy from the grid by around 45 tCO2-eq.

The Powerledger Blockchain (PLBC) proves significantly more cost-effective and efficient than the alternative Ethereum-based blockchain. With an annual total of 816,065 P2P transactions, the operation of the PLBC costs only 1.65 USD compared to the staggering 384,000 USD on Ethereum.

Self Sufficiency

Comparing BAU and LEM, the P2P trading can increase the community **self sufficiency by 5 % to a total of 31 %**, therefore reducing the reliance on the backup grid as shown in Figure 13. Self-sufficiency refers to the ability of the community to generate and meet its own energy needs without relying on external sources.

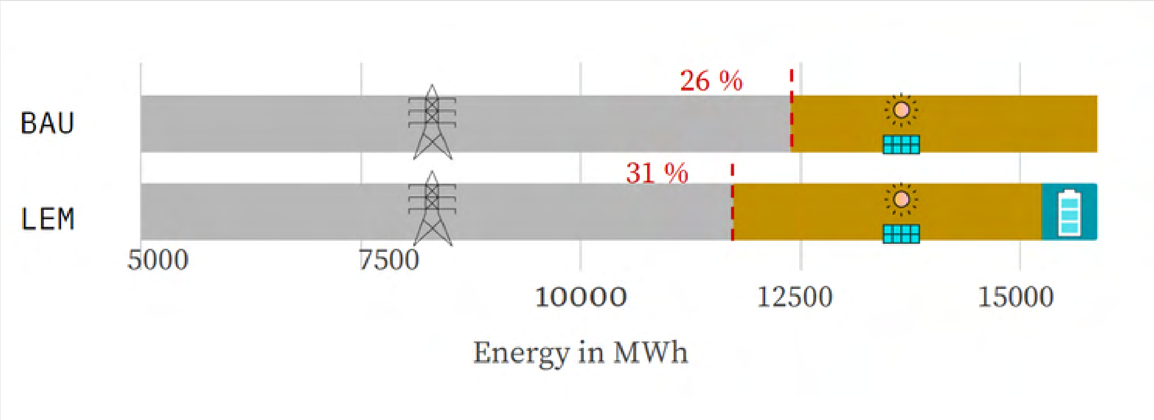
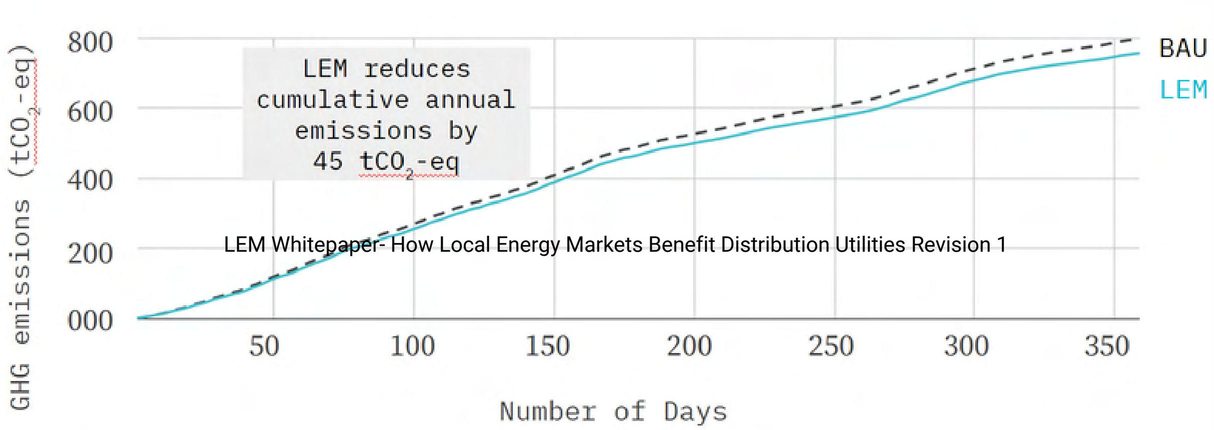


Figure 13: Community Self Sufficiency

GHG Reduction

This increase in self sufficiency is reflected in the amount of cumulative GHG emissions in CO2-eq from electricity consumption. Replacing a substantial amount of carbon intensive grid energy with local solar and battery storage energy can **reduce the cumulative GHG gas emissions annually by 45 tCO2-eq or the equivalent of taking 27 combustion engine cars of the road** as shown in Figure 14. GHG emissions reduction can be enhanced through additional DER capacities.



LEM Whitepaper- How Local Energy Markets Benefit Distribution Utilities Revision 1

Figure 14: Cumulative GHG emissions from electricity consumption

Blockchain Speed and Cost

The annual total number of P2P transactions are 816,065. On Ethereum, storing all transactions would cost a staggering 384,000 USD, while Gen3 PLBC cost a mere 1.65 USD. This difference arises from PLBC's inherently lower fees and **higher transaction speed of 65,000 transactions per second (TPS) [16], compared to Ethereum's 30 TPS [17]** as shown in Figure 15. This superior scalability ensures smooth operation even with our high transaction volume, avoiding costly bottlenecks and delays.

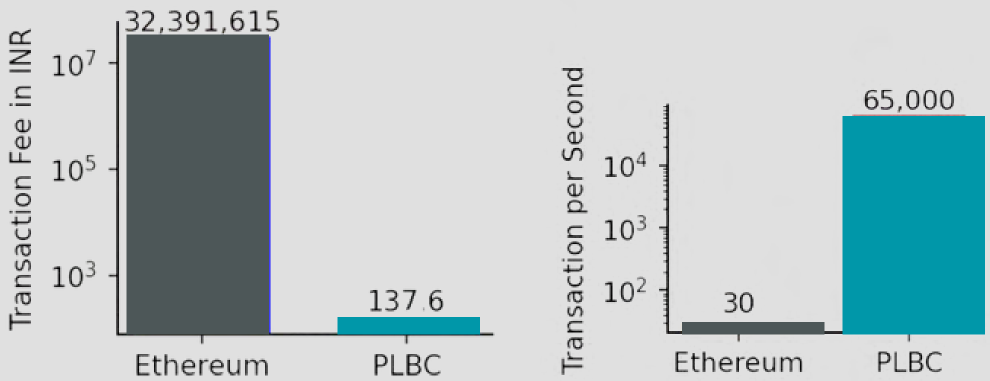


Figure 15: Comparison of Blockchain cost and transactions speed among Ethereum and PLBC

Discussion

Results from this simulation underscore the benefits associated with LEMs and indicate that P2P energy trading including flexible assets such as battery storage can substantially reduce the need for locational network services through demand profile balancing and defer investment required for network upgrades. The results displayed indicate benefits in terms of self sufficiency, electricity cost and demand profile peaks. However the benefits extend beyond these including reduced reverse flow of energy, maintained retailer and network operator margin and environmental benefits such as reduced carbon dioxide emissions from energy consumption.

3.6. LEM Case Study - Conclusion

In conclusion, the results of Powerledger's simulated LEM in India have illuminated the considerable advantages of adopting a P2P trading-based LEM approach over the conventional BAU scenario. Demonstrated results can be further enhanced through flexible loads or electric vehicles incorporated in the LEM. A high level architecture of LEM is shown in Figure 16 The case study shows that heterogeneous communities consisting of different electricity end customer groups can together reap significant benefits from LEM solutions.

The LEM significantly reduces the average electricity bills for participants, **with a substantial 12 % average decrease**. This cost reduction is achieved through both lower buying prices for consumers and higher selling prices for prosumers.

Moreover, the benefits of the LEM extend across all participant categories, with prosumers experiencing the most substantial advantages, including reduced energy bills and accelerated payback periods. This enables close socio-economic communities and is a step towards an optimised decentralised energy system.

1. Powerledger simulated a LEM in India comparing a P2P trading based LEM scenario with a BAU scenario.

2. LEM reduces solar export peak during midday as well as evening demand peaks through the optimised dispatch cycle of a community battery thereby reducing requirements on the network.

3. Additionally, LEM reduces the average electricity bill by 12 %. It allows consumers to buy at reduced prices as well as prosumers to sell at elevated prices thereby incentivising participation in a LEM and installation of DERs.

4. Self sufficiency as well as self consumption are improved by LEM which leads to environmental benefits and contributions to a renewable energy transition.

A group of domestic and commercial electricity users engaging in a LEM can create a socially close community which saves an average of 20 % of electricity cost and consumes increased amounts of local renewable energy.

The reduced reliance on the backup grid leads to lower GHG emissions as less carbon-intensive energy is imported from coal or gas power plants upstream and rather self supplied within the community. Furthermore, the reduced payback period for DERs through LEM incentivises additional installations of solar PV and battery systems or other renewable small-scale DERs, therefore accelerating the energy transition.
Cost of blockchain for securely and transparently storing transaction details are minimal based on Gen3 blockchain applications and do not impact cost savings from engaging with LEM.

The operation of a LEM reduces the energy exchange and reliance on the centralised grid infrastructure thereby enabling reduced requirements on the connecting grid infrastructure such as distribution transformers.

The automatically enhanced distribution of the demand curve reduces the requirement for network services through balancing variable generation resources such as solar with the usually inflexible demand through battery control. This also leads to a reduction in infrastructure requirements thereby enabling the DSO to defer investment and procure infrastructure with lower capacity rating.

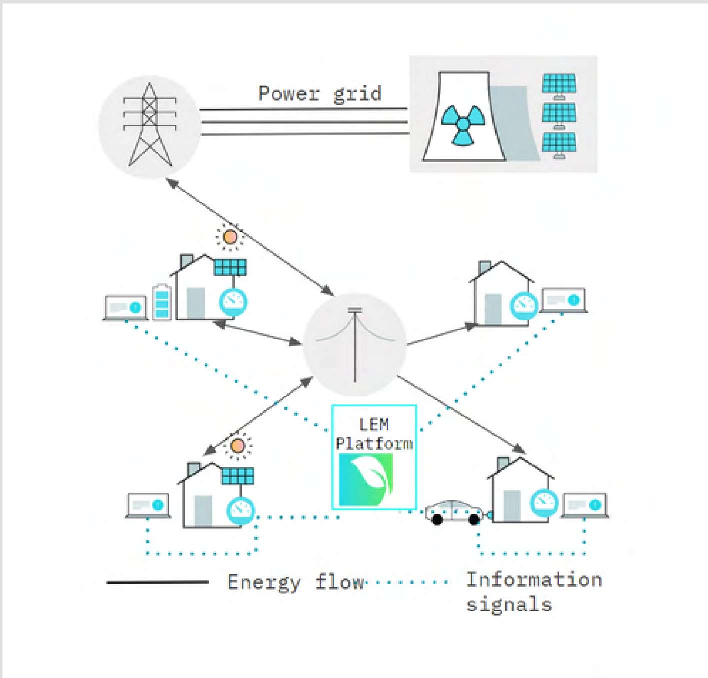


Figure 16: LEM high level structure

In summary, the case study shows that LEMs offer a sustainable, resilient, and cost-effective path toward cleaner energy, local empowerment, and a greener future.

Ultimately, the LEM emerges as a transformative solution that promises economic and environmental benefits for all involved.

3.7. Examples of globally implemented P2P energy projects by Powerledger

Powerledger operates a variety of different P2P energy trading project in multiple countries. A selection of projects are discussed in this section.

The full list of projects can be viewed at powerledger.io/clients.

India - CESC:

The project, a collaboration between Calcutta Electricity Supply Corporation (CESC), India Smart Grid Forum (ISGF), and Powerledger, involved over 1,000 participants in India's largest P2P energy trading project. The project aimed to showcase P2P trading as a market-based alternative to net metering schemes, assessing benefits for both participants and the utility. Involving 213 prosumers and 788 consumers, the project facilitated the transaction of 742.53 GWh of renewable energy over four months. Key financial outcomes included total consumer savings of 2900 USD in five months, a 10% average reduction in energy rates for consumers, and substantial monthly savings for both DISCOM and participants compared to net metering. The study highlighted that P2P trading benefits consumers, prosumers, and DISCOM more than net metering. Moreover, consumers using Powerledger's platform could optimise their benefits by adjusting their trading preferences, with the option to pay a premium for locally sourced, sustainable energy [18].

Spain - Feníe Energía:

In this case study, a new energy community in Almócita, Spain, utilises Powerledger's blockchain-based P2P trading platform to enable residents to securely monitor and trade renewable energy generated locally. This initiative, in collaboration with Feníe Energía and Albedo Solar, aims to enhance energy efficiency and distribute solar energy within the community, thereby supporting local sustainability efforts. The project has an initial solar PV installation of 60kW across public and residential buildings, with plans for expansion. Additionally, a 22 kWh battery storage system will provide renewable energy during less sunny periods and capitalize on fluctuating daily energy prices. The project's success could potentially influence regulatory changes in Spain, promoting P2P energy trading [19].

Thailand - CMU:

BCPG Public Company Limited (BCPG) and Chiang Mai University (CMU) have partnered to transform CMU into a 'Smart University' with a blockchain-based energy trading system. The agreement involves CMU transacting solar energy with Power Ledger as the digital energy partner. This project features solar panels on over 150 university buildings with a combined capacity of 15 MW and a total of over 16 GWh of solar energy generated annually. Prosumers have the ability to allocated heir surplus to a specifically chosen campus building which is aiming to become a net-zero carbon building. The project further aims to foster a circular economy by ensuring no excess electricity or waste, aligning with CMU's goal to be a Smart University using clean energy focusing on technology-driven solutions for environmental issues [20].

Australia - CUB:

The innovative VB Solar Exchange program was developed to assist Carlton & United Breweries (CUB) in achieving their sustainability goals. This pioneering initiative, powered by Powerledger's technology, is the world's first to exchange excess solar energy for a commodity. The program enables participants to efficiently track and trade surplus solar energy for VB beer, enhancing renewable energy usage in the region. This approach significantly cuts down CO_2 emissions by CUB, while participants benefit from receiving discounted VB beer directly at their homes. Powerledger's P2P platform facilitates this exchange, allowing households and businesses to sell their extra solar energy to others on the same electricity grid. The entire process is recorded on Powerledger’s blockchain platform, ensuring an immutable and transparent audit trail. This case study demonstrates a unique and effective blend of sustainability and consumer reward [21].

4. Applications and Benefits of Local Energy market

4.1. How LEMs Operate to facilitate P2P energy transactions

LEMs can be placed anywhere in the electricity network where a set of end-users wants to exchange deficient and surplus energy within a community. LEMs have a geographical boundary under a medium voltage substation to keep the energy within the area, and are particularly useful in network issues, such as congestion. Participants mainly consist of residential customers but can also include commercial and industrial (C&I) customers connected to the lower-voltage network. A LEM incorporates different types of participants of all socio-economic layers: pure consumers, prosumers with solar PV, prosumers with solar PV and BESS, electric-vehicles (EV), pure producers or stand-alone BESS such as community BESS.

The LEM is an automated platform and can be administered directly by a grid operator. Participants enroll in the LEM via their energy retailers and are classified according to their distinct needs and functions within the LEM. The cloud platform hosts the necessary energy management systems, trading and forecasting services. Based on meter data, forecasts are generated for every user in an automated manner. Participants set their preferred trading prices via a user interface. This enables them to have a degree of control over the cost of their received energy. The LEM promotes P2P trading between multiple buyers and sellers. The platform automatically matches buy and sell offers in forward facing time intervals based on forecasts.

After the trading has finalised, the platform controls the on-site DER assets in real-time to carry out the agreed trades and create changes in the energy profile of the community. Smart meter interval data verifies the transacted export and import volumes and is used for final settlement. The transacted energy volumes at the corresponding contract rates are transferred to the retailer(s) to be netted at the end of each billing cycle and to reflect in the billing statement to the participant. The simplified LEM trading sequence is shown in Figure 17.

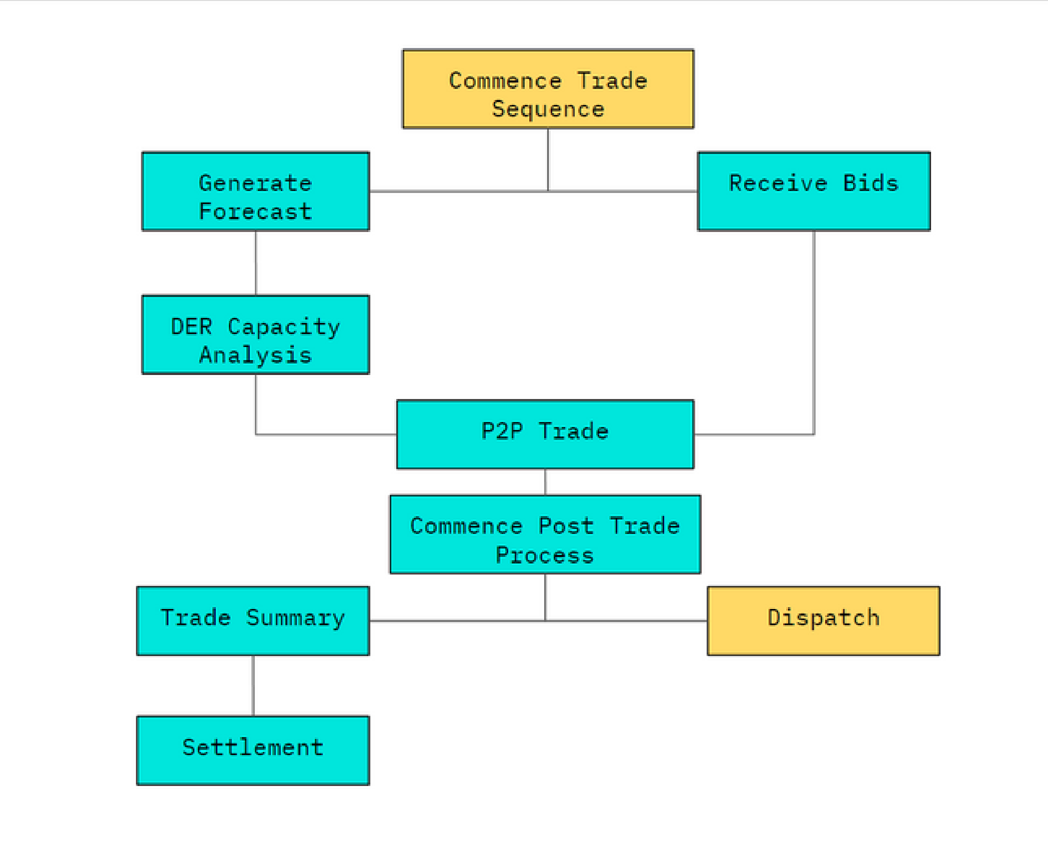


Figure 17 LEM Trade Sequence

4.2. The LEM platform is a modular set of individual services

The LEM platform ecosystem consists of multiple services which collectively perform tasks from generating forecasts to matching buyers and seller, over to final outputs such as real-time DER control and customer billing. The platform provides multiple interfaces to third-party system and offers a high degree of customisation to perform the dedicated tasks under various circumstances.

The modularity of the LEM platform allows it to seamlessly alter the composition of individual services and allows enhanced integration with third-party systems and services which can even replace services within the trading platform itself, such as the forecasting service. Figure 18 shown the LEM platform services and their connection detail.

On a high level, the LEM platform operates under the following sequence: (1) BESS controllers are responsible for gathering crucial data such as state of charge (SOC) and energy rates.

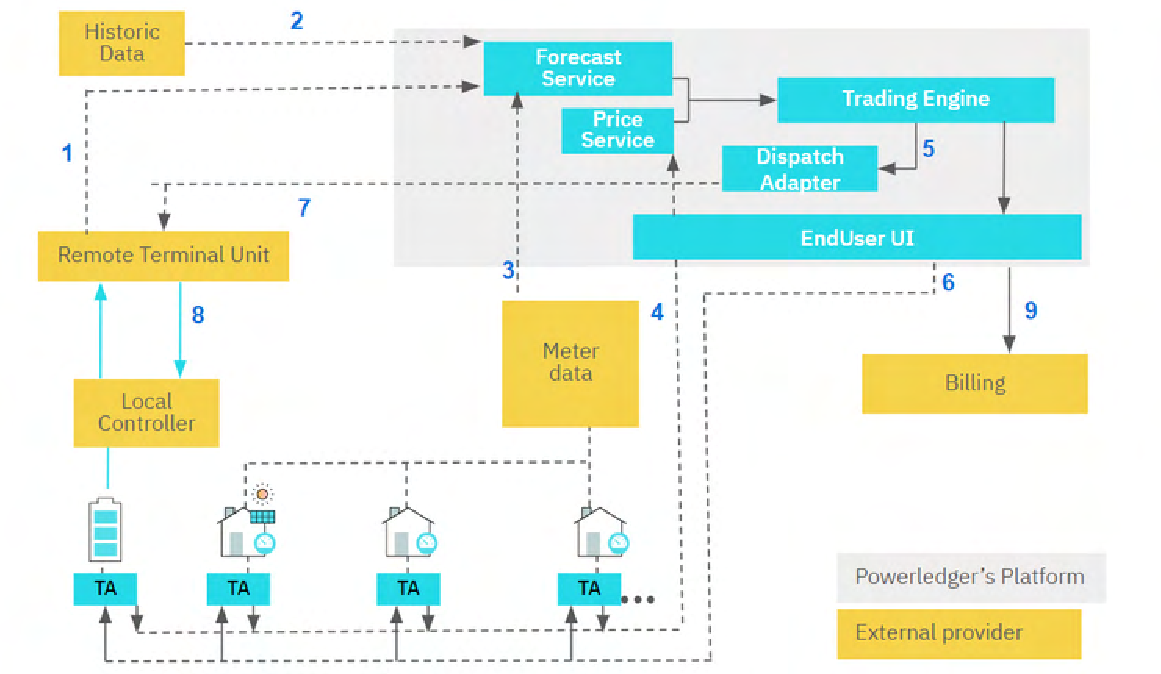


Figure 18 LEM Platform services and connections

(2) Additionally, historical meter data is uploaded to the LEM's trading platform to establish baseline forecast profiles for participants.
(3) Periodically, meter data from the participants is transmitted to the trading platform via secure protocols, ensuring a steady flow of current information for forecasting and settlement.
(4) Participants interact with the platform through a user interface to place their buy and sell orders.
(5) The trading engine then undertakes the task of formulating trades based on the input data, executing contracts through a sophisticated matchmaking algorithm.
(6) The results of the executed contracts are communicated back to the participants, confirming the details of the transactions.
(7) This includes sending dispatch signals to the onsite controllers to manage the energy flow according to the trade agreements.
(8) The dispatch signals are executed in real-time by the BESSs.
(9) Lastly, the outcomes of these dispatches, including meter readings, are integrated into the billing systems for accurate billing and settlement, closing the loop on the LEM's operational cycle.

Looking to the future, the system may incorporate network constraints directly into the optimisation process of the trading engine, enhancing the efficacy of the energy trading.

4.3. LEMs can be implemented in most locations with a minimum technical infrastructure

LEMs operate within the retail energy market layer interfacing with energy retailers, grid operators and end-consumers. This requires no new grid infrastructure as LEMs typically transact energy within the boundaries of the existing electricity network. As LEMs operate ahead of real-time in specific short-term intervals, they require a set of network connected devices including smart meters and DERs such as solar systems and batteries to operate efficiently.

At their core, LEMs primarily need two components: software for managing trades and hardware to monitor and control energy flow.

1. Software Platform:
The heart of an LEM is a digital platform that is easy to navigate (Figure 19). This software acts like a virtual marketplace, where participants can buy, sell, or trade energy. It is designed to be intuitive, ensuring that all community members, regardless of their technical background, can participate effortlessly. Incorporating blockchain technology, the platform uses smart contracts to automate the trading process. These are pre-programmed agreements that execute trades automatically when certain conditions are met, ensuring transparency and trust among participants.

The software securely handles all the transaction data, ensuring privacy and data protection. This includes recording energy production, consumption, and prices in real-time.

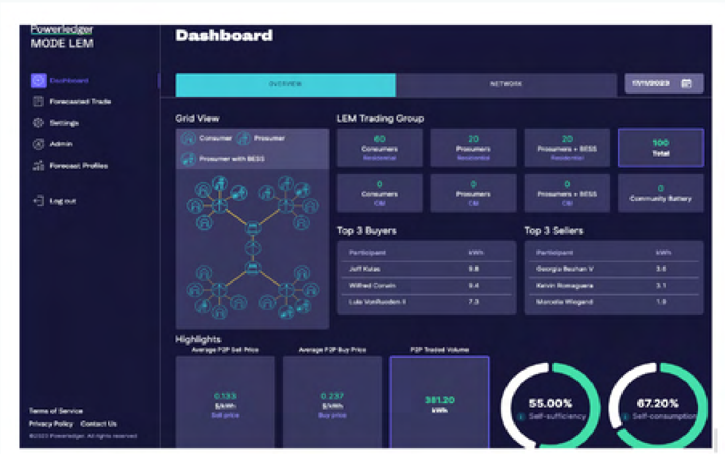


Figure 19 LEM software platform overview

2. Hardware Requirements:
Smart Meters: The only significant hardware required for LEMs are smart meters. These advanced meters record energy usage and production in real-time and communicate this data to the software platform. Most modern energy infrastructures are already equipped with or transitioning to smart meters, making this requirement quite standard.

Renewable Energy Sources: The effectiveness of LEMs is maximised when participants use DERs like solar panels or BESS. To remotely dispatch controllable assets such as BESS specific communication protocols must be in place.

One additional requirement is the existence of a regulatory framework allowing the transfer of electricity between peers such as the Clean Energy Package in the EU [22] or the guidelines in favour of P2P implemented by the MNRE and CERC in India.

In summary, setting up a LEM is less about heavy technical installations and more about leveraging smart, user-friendly software combined with existing or minimally augmented hardware. The goal is to create a system that is accessible to all, promoting sustainable energy use and community engagement without the need for in-depth technical knowledge.

4.4. LEMs mitigate the 'duck curve' challenge and enhance the grid security

The duck curve represents the mismatch between electricity demand and solar Variable Renewable Energy (VRE) availability throughout the day, with solar peaking at noon and demand surging in the evening.

LEMs facilitated by P2P energy trading are pivotal in addressing this challenge faced by DSOs/DNSPs. They enable surplus electricity trading thereby reducing the curve's extremities.

The importance of solutions such as LEM stem from the existing and continual challenge facing DSO/DNSPs commonly referred to as the "duck curve". First published in 2013 by the California Independent System Operator (ISO) [23], the duck curve depicts the difference in electricity demand and the availability of solar VRE throughout the day.

While solar produces peak output at noon, peak demand is in the evening when most residents return from work and power up home appliances, resulting in an imbalance throughout the day. As depicted in Figure 20 with the example of South Australia, the peaks (maximum demand around 18:00) and valleys (maximum electrical output at noon) on the chart resemble a duck head and belly, hence the term duck curve.

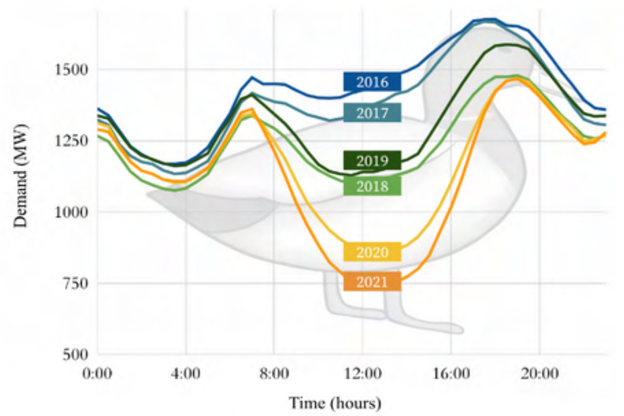


Figure 20 Duck curve in South Australia [24]

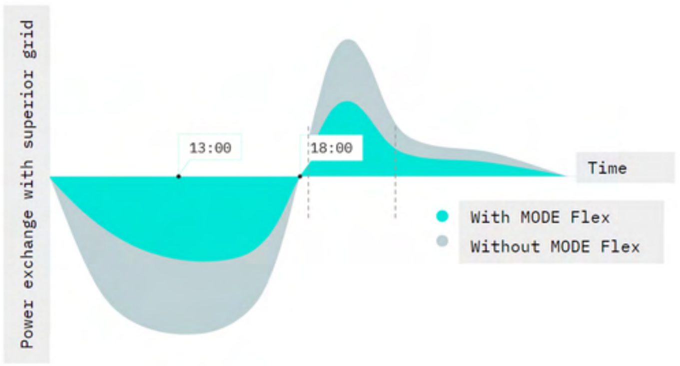


Figure 21 Energy exchange with and without P2P trading

Figure 21 shows the importance of LEMs, enabled by P2P energy trading, and how they can support the grid by reducing supply. During peak demand, when participants are able to trade their surplus electricity and utilise peers' battery systems or flexible demand shift, the head of the duck is minimised.

During the day when surplus solar is available, the batteries charge on their peers' solar, **hence the minimisation of the duck's belly**. The switching in and out of stored battery energy helps to manage grid power flows and is achieved automatically by the LEM software platform. This underlying theory of P2P enables LEMs to reduce the overall need for flexibility services and mitigate resource constraints, such as the duck curve.

Benefit to grid security
Moreover, these layers enhance grid security by ensuring minimum demand thresholds are met, preventing negative prices in wholesale markets which can discourage investment in new renewable generation capacities. This approach offers a localised solution, benefiting all stakeholders. Vendors such as Power Ledger believe that getting as close to the source of grid challenges as possible is the most effective method to address any congestion, demand peaks, frequency and/or voltage issues. In essence, LEMs represent the most localised way to help balance the grid, providing bidirectional value to prosumers and consumers as well as the DSO/DNSPs.

4.5. Diverting excess solar energy to peer batteries creates a flexible load profile

Historically, generation has followed load consumption curves, as generation from centralised thermal generators is controllable and adaptable to changing load requirements.

Less flexible and volatile generation from wind and solar has only limited ability to follow load requirements as it is mainly dependant on current weather and changes output rapidly with changing weather conditions. To get the maximum out of variable renewable energy, networks have to create a demand that is adaptable and can follow the availability of solar and wind resources, which is achieved through a solution like LEM.

If the issue of inflexible generation such as solar and wind is not met from the demand side, the effect on grid security is visible through the level of observed minimum demand and rapidly changing energy availability through changes in weather conditions affecting the output of VRE. Minimum demand is the demand mainly met by the minimum number of online synchronous generators that must be available to keep the system stable. **With rising solar, minimum demand decreases resulting in periods of critical online dispatchable generation.**

These time periods, especially on weekends with low consumption overall, can also set off negative prices in the wholesale markets. This is commonly seen in Australia when synchronous generators are forced to offer energy at negative prices just to stay online.

The control of flexible loads or batteries through solutions such as LEM increases load during main solar hours. This reduces solar exports at the grid nodes and helps to maintain or even increase the minimum demand. It may be noted that displacing centralised energy over the year(s) through orchestration of DERs does not clash with DER power supporting central generation during specific low-load hours. This solves the problem of minimum demand, keeping a certain number of synchronous machines online.

LEMs can improve minimum demand levels and CapEx driven network investment by diverting solar excess to existing DER capacities. They provide an automated solution to uncontrolled grid exports.

The depicted solutions complement Time-of-Use (ToU) which encourage consumption during low-load periods such as night or midday. Load shifting through ToU tariffs, aided by smart appliances and LEMs, offers immediate benefits, reducing the need for costly grid batteries and redispatch measures. ToU tariffs additionally greatly enhance the benefits from LEMs specifically for battery owners which can arbitrage on the different price points.

For the effect to be felt on a grid level, smart appliances and home energy management systems will need widespread adoption which is incentivised through LEM due to increased investment returns [25]. LEMs that are scaled can reduce the need for rising capacities for grid balancing services usually provided CapEx driven gas peaking plants or increasingly utility-scale batteries. Rather, they replace this approach with decentralised DERs owned by end-customers.

4.6. Create socially close energy communities to provide the basis of a decentralised energy system

LEMs offer the opportunity to lower energy costs through collective bargaining and shared renewable resources, putting money back in residents' pockets. The communities empower individuals to actively participate in sustainable practices, creating a sense of environmental responsibility and social belonging.

Beyond financial savings, energy communities promote clean energy adoption, reduce greenhouse gas emissions, and contribute to a more resilient energy infrastructure.

LEMs are a powerful force for positive change in the lives of individuals and communities alike. Figure 22 shown the benefits LEM as decentralised energy system brings for the community.
One of the foremost benefits is the **support of local generation assets** such as solar PV, wind and residential or community batteries. These assets receive an increased return on investment through LEM, therefore incentivising community investment.

LEMs are at the forefront of sustainability, fostering a deep sense of **environmental responsibility**. Through the generation of clean, renewable energy, these communities contribute significantly to mitigating the impacts of climate change and preserving the environment for future generations.
In addition they offer a degree of **energy independence**. With energy storage systems, they utilise a maximised amount of local generation thereby reducing the amount of energy needed from the backup grid.

Through **collective self consumption** mechanisms in a LEM members actively participate in energy decisions, building a sense of ownership and cooperation that transcends energy-related matters.
Community engagement within LEMs empowers individuals to actively participate in shaping their energy future, making informed decisions about energy generation and consumption. This engagement not only strengthens social bonds but also promotes a collective commitment to sustainable practices and responsibility, leading to a more interconnected community.

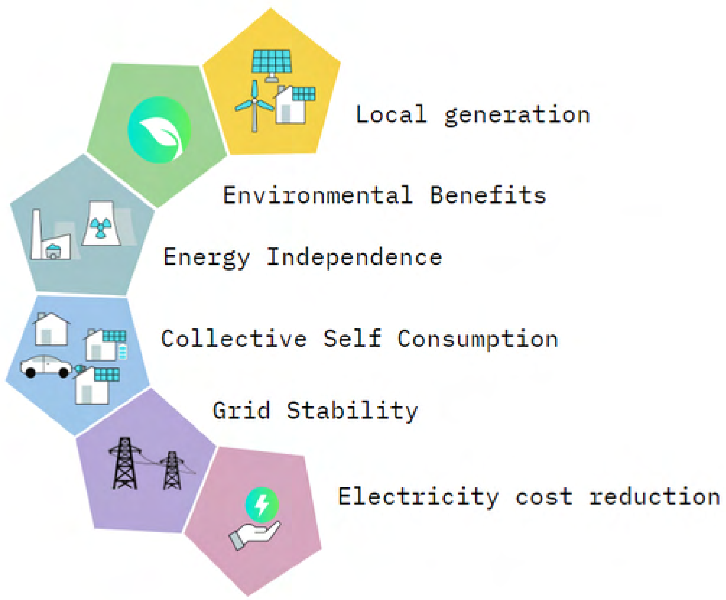


Figure 22 LEM benefits for the community.

LEMs offer the potential for substantial cost savings. By coming together and collectively negotiating energy prices, members of these communities often enjoy lower energy bills, freeing up financial resources for other essentials or investments.

4.7. LEM benefits at a glance

1. LEMs benefit prosumers with higher returns and consumers with lower energy costs.
2. DNSPs benefit by reducing congestion and improving power quality at a lower cost than infrastructure investments.
3. DERs within LEMs cut grid exports and imports, easing congestion and lowering capital expenditures.
4. Combining LEMs with flexibility markets reduces incentives for DNSPs to purchase flexibility services, resulting in significant savings.
5. Matching of supply and demand increases self sufficiency of the LEM community therefore reducing reliance on wider network.

Implementing a LEM results in financial benefits for the prosumers and consumers as well as the DSO. By participating in a LEM, prosumers can achieve a greater return on investment while all consumers in the LEM are offered lower energy prices. The automated platform helps a DER owner in decisions throughout the day: dispatch to peers, store excess generation in stationary batteries, recharge an EV, buy power from the grid, participate in demand response, etc. Participants in the market are now able to reap the benefits of optimized decisions that maximize economic returns on their investment.

Though LEMs offer financial benefits across the system, DNSP/DSOs are particularly interested in their ability to balance demand, reduce power flow congestion, and maximise power quality - all at the lowest possible cost. Engaging in the LEM not only reduces the energy bill but also helps reduce the payback period of a DER procurement thereby incentivising participants to procure a DER such as solar or BESS. This increase in DERs in turn improves the benefits for all participants reducing electricity expenses further.

Historically, DNSP/DSOs have invested heavily in infrastructure to accommodate growing load and to avoid potential congestion. Using LEMs can reduce investment needed for balancing supply and demand on a local level and within the existing infrastructure. Controlled operation of the DER assets relieves congestion and in turn helps to defer investment on primary assets such as transformers or feeders. When LEMs are utilised in support of layer 3, the flexibility market, DSNP/DSO's experience financial benefits in the form of reduced budgeted incentives for purchasing flexibility services. It is estimated that operation of roughly five (5) LEMs with one thousand participants could offset the need for 1 MW of flexibility services and save corresponding incentives for the network operator.

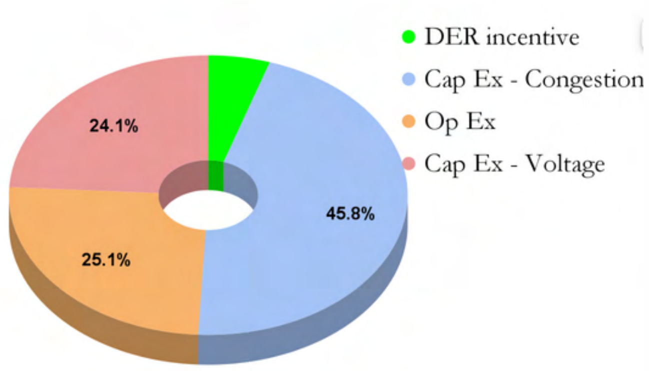


Figure 23 DSO CAPEX Budgets: A Typical Example

As displayed in Figure 23, capital costs linked to congestion and voltage management represent almost 70% of a typical DSO's annual budget. Typically, annual budgets have a 75:25 ratio of capital expenditures to operating expenses. In a recent annual distribution investment budget plan, the company planned to invest between $708 million and $865 million per year in capital projects on the electrical distribution system, a large driver of this being reliability.

This planned investment is heavily weighted by equipment and infrastructure investment including lines, cables, and substation to account for increases in load growth and aging infrastructure. Other portions of the capex budget include grid modernization and reliability efforts such as targeted circuit improvements and pole replacements to reduce SAIDI and CAIDI, as well as augmenting systems to improve voltage management and congestion. Operating expenses planned during this time period range between $221 and $308 million per year.

5. Conclusion

5.1. Conclusion

Utilities perched on the fence of progress, it's time to descend into the realm of the Local Energy Market. The energy landscape is evolving, demanding a departure from the traditional. Sitting idle means missing the opportunity to lead in this transformative era.

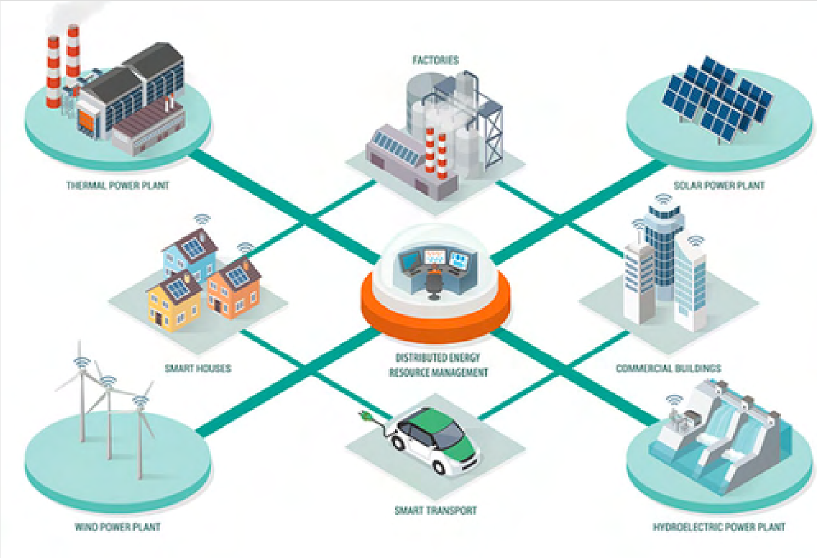
Step off the fence, engage in the Local Energy Market, and be the catalyst for a greener, more dynamic future. LEMs are a win-win-win for all stakeholders including yourselves and your customers.

In conclusion, this whitepaper emphasises the wide range of contributions of Local Energy Markets.
It showcases how LEMs, by integrating innovative technologies like blockchain, are pivotal in transforming energy distribution, enabling more efficient and decentralised systems. LEMs significantly contribute to grid stability by managing and reducing congestion, especially in areas with high shares of variable renewable energy and underdeveloped grid infrastructure. LEMs offer an efficient solution to the effects of variable solar PV output on grid stability by utilising energy storage or demand response to balance local demand and supply.

Economically, LEMs offer notable cost savings, encourage local investments and foster economic growth in communities. Environmentally, they are instrumental in reducing greenhouse gas emissions, promoting sustainable energy use, and contributing to global environmental goals.

The empowerment of communities through increased energy self-sufficiency is a key highlight, as LEMs enable residents and businesses to actively participate in energy production and trading. This shift from a centralised to a decentralised energy model not only enhances local energy resilience but also paves the way for a cleaner, more sustainable energy future.

LEMs create socially and locally close communities and encourage the utilisation of shared resources such as DERs. The above stated benefits are supported via a case study in the Indian context which highlights the various benefits on the participants, the utility and the grid as a whole.



Further, the whitepaper underscores the critical role of regulatory support and technological advancement in realising the full potential of LEMs.

The role of blockchain and smart contracts in portrayed which offer significant opportunities in the energy landscape in terms of their immutability and transparency which generates a layer of trust between peers in a decentralised network.

The successful implementation of these markets is shown to be crucial in achieving a more sustainable, efficient, and equitable energy landscape and can be one of the missing building blocks to achieve a higher level of electrification and a quick transition to net-zero energy consumption.

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7. Appendix

1. LEM Local Energy Markets
2. TE Transactive Energy
3. P2P Peer to Peer power sharing
4. BESS Battery Energy Storage System
5. FiT Feed-in Tariff
6. DER Distributed Energy Resources
7. PV Photovoltaic
8. OPEX Operational expenditures
9. CAPEX Capital expenditures
10. AGC Automatic Generation Control
11. DNSP Distribution Network Service Provider
12. VPP Virtual Power Plant
13. EV Electric Vehicle
14. DSO Distribution System Operator
15. ToU Time of Use
16. DMO Default Market Offer
17. FCAS Frequency Control Ancillary Services
18. DOE Dynamic Operating Envelope
19. GHG Greenhouse Gas
20. TSO Transmission System Operator
21. DISCOM Distribution Company
22. TPS Transactions Per Second
23. PLBC Powerledger Blockchain
24. EU European Union
25. MNRE Ministry of New and Renewable Energy
26. CERC Central Electricity Regulatory Commission
27. VRE Variable Renewable Energy